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Divergent Decomposition Patterns of Leaf Litter and Fine Roots from an Urban Forest in Mid-Subtropical China

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Abstract: Litter decomposition plays a pivotal role in carbon (C) and nutrient cycling in terrestrial ecosystems. However, little is known about the litter decomposition processes and nutrient dynamics in urban green space. In this study, the decomposition and nutrient dynamics of leaf litter and fine roots from *Cinnamomum officinarum* Nee ex Wall. and *Elaeocarpus decipiens* Hemsl. were studied in an urban forest in subtropical China. The results showed that the leaf litter mass loss, and nitrogen (N) and phosphorus (P) mineralization of *E. decipiens* were faster than that of *C. officinarum* in the first 180 days, but in the whole decomposition period, the leaf litter decomposition constant of *C. officinarum* was higher than that of *E. decipiens*. There was no difference in fine root decomposition constant and P mineralization, although the fine root N immobilization was higher relative to *C. officinarum* during the 90th to 270th days. Additionally, both the leaf litter mass loss, decomposition rate, and nutrient mineralization were faster than fine roots for these two tree species. The soil microbial biomass showed positive effects on leaf litter decomposition and negative effects on fine root decomposition. The correlation analysis indicated that initial litter quality, soil physicochemical properties, and microbial activity mainly affected early-stage litter decomposition and nutrient mineralization. Also, the leaf litter production and N and P storages of *E. decipiens* were higher than that of *C. officinarum*, suggesting faster decomposition rate and nutrient return for *E. decipiens* leaf litter. Consequently, we propose that tree species with fast nutrient return, such as *E. decipiens*, could be introduced to urban green space with pervious surfaces in respect of the nutrient balance. This work improves the understanding of litter decomposition and nutrient cycling and promotes the management for urban green space.

Keywords: litter decomposition; nutrient mineralization; tree species; litter quality; soil microbes; urban environment; street trees; urban forest management

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1. Introduction

Litter decomposition is vital for carbon (C) and nutrient cycling in terrestrial ecosystems, and has been studied intensively [1]. Aboveground litter, such as leaf litter, has made a non-negligible contribution to soil organic C (SOC) sequestration [2]. Belowground litter, such as fine roots, productivity may account for 30% of net primary production [3]. Also, the fine roots input into soil C are 1.2 times greater than that of leaf litter [4]. However, information on above and below-ground litter decomposition in urban green space ecosystems is scarce [5]. With the rapid development of the economy, the ecological environment in many cities has been further improved, and the proportion of urban green space has been increasing [6]. More urban forests and green spaces with trees have been established extensively [7]. Understanding the decomposition and nutrient dynamics of litter is important for the management and protection of urban green spaces [8].

Litter decomposition is a fundamental ecological process that regulates nutrient and C cycling [9,10], which can provide an indicator of ecosystem function and health at various levels. Litter substrate quality, soil microbial activity, and climate affect leaf litter and fine root decomposition [11,12]. Litter quality and microclimate can explain over 31% of the variance in litter decomposition in subtropical plantations [13]. Also, fine roots seem to be more recalcitrant than leaf litter decomposing at a significantly slower rate than leaf litter for the same species [14]. The initial litter nitrogen (N), phosphorus (P), and lignin were significantly correlated to litter mass loss [15–17]. Furthermore, urban green space is characterized by different abiotic and biotic factors. Understanding ecological processes and environmental changes in urban green space is an important challenge to secure human well-being [18]. For instance, soil temperature and soil bacterial diversity were higher in urban soils than in rural soils [19,20]. These abiotic and biotic factors may affect the litter quality, thus changing the food source for decomposers [18]. The changes in litter quality and microbial decomposers would alter the processes of litter decomposition and nutrient mineralization. However, it is less well known that decomposition responds to the novel environments created by urbanization [21].

Decomposition has been less studied in urban environments, and the previous studies on urban decomposition mostly focused on comparisons along urban to rural gradients [5] and on the effects of urban pollution on litter properties [22]. Decomposition rates were sometimes more rapid in the urban environment, likely because of warmer soil temperatures and more macro-faunal decomposers [23,24]. But in another study, the decomposition rates were lower in the urban environment, perhaps because of the reduction in fungal abundance in urban soils [19]. Unfortunately, the litter nutrient dynamics were frequently neglected, although it was studied on pavements with impervious surfaces [8]. Moreover, information on below-ground litter, such as fine root decomposition and nutrient mineralization, is very scarce in urban green space. The mechanisms of the above- and below-ground litter decomposition and nutrient dynamics in urban green space are still poorly understood.

Cinnamomum officinarum Nee ex Wall. and *Elaeocarpus decipiens* Hemsl. are evergreen broad-leaved tree species, that are frequently applied to landscaping tree species and street trees in subtropical China. The leaf litter from landscaping tree species and street tree are often removed at the sites of streets, parks and campus [25]. *C. officinarum* and *E. decipiens* differ in litter chemical properties, and higher C and lower P concentrations were observed in the senescent leaves of *C. officinarum* [26]. To better manage urban green space, we investigated the patterns of leaf and fine root litter decomposition and nutrient mineralization characteristics of *C. officinarum* and *E. decipiens* in an urban forest in mid-subtropical China. We hypothesized that (1) leaf litter decomposition and nutrient release would be faster than fine roots, and (2) the leaf litter and fine root decomposition and nutrient release of *E. decipiens* could differ from *C. officinarum* due to the differences in litter quality.

2. Materials and Methods

2.1. Study Site

This study was conducted at the Biological Garden of Hunan University of Science and Technology (112.92° E, 27.92° N), located in Xiangtan City, Hunan Province in central China. It has a typical subtropical monsoon climate with a distinct wet (from April to September) and dry season (from October to March). The mean annual precipitation is 1320 mm, and the mean annual temperature is 17.2 °C. The soil is classified as Ultisol developed from sandstone [27]. The two studied tree species were planted on homogenous, degraded hilly land in the 1980s. The mean altitude is approximately 63 m in this region.

2.2. Experimental Design

Experimental plots (10 m × 100 m) were established on the side of the road in an urban forest with *C. officinarum* and *E. decipiens* in March 2021 with four replicated subplots

(5 m × 4 m) for each tree species, respectively. Both *C. officinarum* and *E. decipiens* on the side of the road were considered street trees in this study. The distance between two adjacent subplots for the same tree species was more than 5 m. The fresh leaf litter and fine roots (diameter < 2 mm) of *C. officinarum* and *E. decipiens* were collected from two sites around the experimental plots in January 2021, respectively. The fine roots were dug and then selected by hand using forceps. Thereafter, all leaf litters of each species were mixed homogeneously, air-dried, and placed into litter bags (20 cm × 20 cm) made from polyvinyl screens. To alleviate the effect of the mesh size of the litterbag on soil biota and insects, the mesh size of one side was 0.5 mm and the other side was 2.0 mm, which was faced up in order to enable access for some soil biota, insects, and fungal mycelium [27]. Each litterbag was filled with 8.00 g (oven-dried weight) of leaf litter from *C. officinarum* or *E. decipiens*. Nine litterbags containing the leaf litter of each species were placed on the surface of the mineral soil horizon after removing the litter layer in each subplot. In total, 72 leaf litterbags (36 per species) were prepared for leaf litter decomposition. In addition, the collected fine roots of *C. officinarum* or *E. decipiens* from the same plot were mixed to obtain a uniform mixture before placing them in the litterbags. The litterbags for fine root decomposition (10 cm× 10 cm) were constructed from a polyvinyl screen with a mesh opening size of 0.1 mm to retrieve the fine root residues. Each bag was filled with 1.50 g (oven-dried weight) of fine roots from the same tree species. Nine litterbags with the fine roots of *C. officinarum* or *E. decipiens* were buried in the soil at an angle of 45° with a depth of 10 cm in each subplot, giving a total of 72 litterbags (36 per species) for fine root decomposition. The soil temperature and moisture content at 0–5 cm were measured semimonthly with a portal soil thermometer. In addition, leaf litter production was collected monthly in 1 m × 1 m baskets constructed of plastic screening with 1 mm mesh from March 2021 to March 2022, four baskets for each plot.

2.3. Litter Decomposition and Sample Analyses

The decomposition of leaf litter and fine roots were initiated on March 1 and 16, 2021 and lasted for 450 days and 465 days, respectively. One litterbag was retrieved from each subplot firstly on March 16 and 31, 2021 for leaf litter and fine roots, respectively, corresponding to the 15th day of decomposition. They were then retrieved on the 30th, 60th, 90th, 120th, 180th, 270th, 360th, and 450th/465th day of leaf litter and fine root decomposition, respectively. The retrieved leaf litters were cleaned using forceps and the retrieved fine root samples were cleaned with tap water. They were dried in an oven at 65 °C for 72 h and weighed to calculate the proportion of litter mass remaining (LMR), respectively. The decomposition rates of leaf litter and fine roots were determined by the proportion of litter mass remaining. In addition, the leaf litter collected monthly from baskets was taken back to the laboratory, oven-dried for 72 h at 65 °C, and weighed to calculate the leaf litter production. Successively, the leaf litter was ground for chemical property analysis. The C, N, and P concentrations of retrieved litters and leaf litter collected monthly were determined by the potassium dichromate oxidation method, the Kjeldahl method, and the Mo-Sb colorimetric method, respectively [28].

2.4. Soil Samples Collection and Analyses

At the beginning of this experiment, the mineral soil samples (0–10 cm depth) were collected with 5 cores and combined into a pooled sample for each subplot, 8 samples in total. The surface litter was removed carefully when the soil sample was taken. Soil samples were thoroughly homogenized by sieving with a 2-mm sieve. Visible plant roots, rocks, and soil macrofauna in soils were removed before analysis. Each soil sample was divided into two subsamples, one for soil physicochemical properties analysis and the other for soil microbial biomass determination. SOC concentration was determined by the potassium dichromate oxidation method [28]. Soil moisture content (SMC %, moisture content per 100 g dry soil) was measured by the gravimetric method, which is oven-drying for 24 h at 105 °C. Soil total nitrogen (TN) concentration was determined with the Kjeldahl

method following concentrated sulfuric acid digestion [28]. Soil total phosphorus (TP) concentration was determined by the Mo-Sb colorimetric method following concentrated sulfuric acid digestion [28]. The soil microbial biomass and community structure were characterized by phospholipid fatty acids (PLFAs) analysis [29]; the details are included in Chen et al. [27].

2.5. Data Analysis

The proportion of litter mass remaining (LMR, %) was calculated with litter residues oven-dried weight divided by initial litter oven-dried weight. That is, LMR (%) = interval weight of litter $\times$ 100/W_0, where the W_0 is the initial weight of litter in each bag (W_0 = 8.00 and 1.50 for leaf litter and fine roots, respectively in this study). In addition, an exponential decay model was used to calculate the decomposition rate [27]: $X = a \times e^{-kt}$, where X is the fraction of initial litter remains at time t (year), a is the simulation parameter, e is the base of the natural logarithm, and k is the decomposition constant (g g^{-1} $year^{-1}$) during the whole or different decomposition periods. Nutrients remaining (%) were calculated with the nutrient storage of leaf litter/fine root residues divided by initial leaf litter/fine root nutrient storage. The nutrient storage of the leaf litter production was calculated by leaf litter production multiplying their nutrient concentrations. The studied parameters in each replicated subplot were calculated separately, and the mean value was applied to the tables and figures.

One-way ANOVA and multiple comparison analysis (LSD) were performed to explore the difference in initial chemical properties of leaf litter/fine roots between the *C. officinarum* and *E. decipiens* soil and the effects of tree species on litter decomposition constant, soil microbial biomass, leaf litter production, and leaf litter nutrient storage. Repeated measured ANOVA (RM-ANOVA) was employed to test the effects of tree species on leaf litter/fine root decomposition (mass remaining, %) and nutrients (C, N, and P) remaining. The Pearson correlations analysis was applied to test the effects of initial soil properties, soil microbial characteristics, and litter initial chemical properties on the decomposition and nutrient dynamics of leaf litter and fine roots, respectively. All statistical analyses were carried out with SPSS 18 (SPSS, Inc., Chicago, IL, USA), and statistical significance was determined at $p < 0.05$ level.

3. Results

3.1. The Initial Soil Physicochemical Characteristics and Initial Litter Quality

One-way ANOVA showed that the initial pH and SOC concentration were significantly higher in the *C. officinarum* plot than in the *E. decipiens* plot (p = 0.003 and 0.008, respectively; Table 1). The initial soil TN and TP in the *C. officinarum* plot did not differ from that in the *E. decipiens* plot (p = 0.071 and 0.360, respectively). In addition, there were no significant differences in initial soil C:N, N:P, and C:P between the *C. officinarum* and the *E. decipiens* plots (all $p > 0.05$). Tree species did not significantly affect the initial biomasses of total microbial, bacterial, fungal, arbuscular mycorrhizal fungal (AMF), and actinomyces and the ratio of fungal to bacterial biomass, although the total microbial and bacterial biomasses in the *C. officinarum* soil were slightly higher than those in the *E. decipiens* soil (p = 0.079 and 0.067, respectively; Figure 1a,b). RM-ANOVA showed that the soil moisture content in the *C. officinarum* plot was higher than that in the *E. decipiens* plot (p = 0.014, Table 1), but the soil temperature at the 0–5 cm soil layer did not differ between the *C. officinarum* and *E. decipiens* plots.

Table 1. The initial soil physicochemical properties (mean $\pm$ SE, n = 4) and annual mean soil temperature and moisture content (n = 24). F and p values are the results of one-way ANOVA.

	C. officinarum	***E. decipiens***	**F-Value**	***p*-Value**
pH	5.31 $\pm$ 0.12	4.48 $\pm$ 0.07	27.93	0.003
SOC (mg g^{-1})	22.90 $\pm$ 2.20	13.10 $\pm$ 1.20	15.33	0.008

Table 1. *Cont.*

	C. officinarum	*E. decipiens*	F-Value	*p*-Value
TN (mg g^{-1})	1.58 ± 0.21	1.00 ± 0.16	4.80	0.071
TP (mg g^{-1})	0.27 ± 0.02	0.22 ± 0.05	0.98	0.360
C:N	14.81 ± 1.19	13.85 ± 1.87	0.19	0.681
N:P	5.98 ± 0.64	4.91 ± 0.67	1.32	0.295
C:P	86.29 ± 4.48	68.24 ± 13.45	1.62	0.250
ST	20.41 ± 1.38	20.51 ± 1.41	0.52	0.500
SMC	26.40 ± 2.00	22.05 ± 1.56	11.73	0.014

Note: SOC, TN, TP, C:N, N:P, C:P, ST and SMC refer to the soil organic carbon, soil total nitrogen, soil total phosphorus, the ratios of soil carbon to nitrogen, nitrogen to phosphorus, and carbon to phosphorus, soil temperature, and soil moisture content.

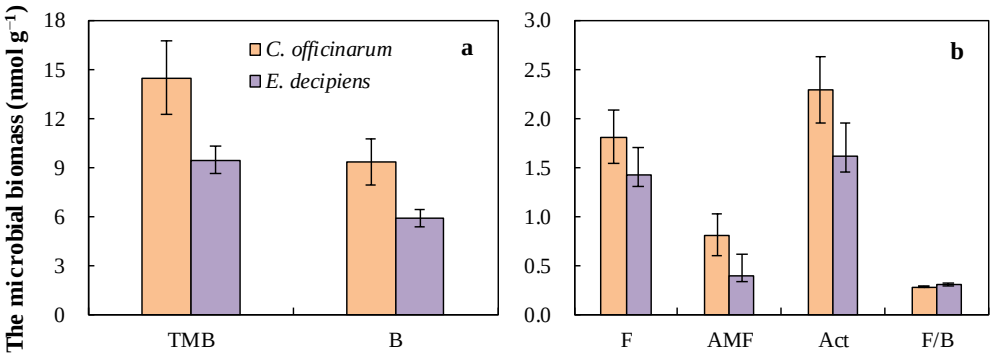

Figure 1. The initial soil microbial biomass represented by PLFAs methods in the 0–10 cm soil layer. (**a**) total microbial biomass (TMB) and bacterial biomass (B); (**b**) the biomasses of fungi (F), arbuscular mycorrhizal fungi (AMF), and actinomycetes (Act), and the ratio of fungal to bacterial biomass (F/B). Each column is the mean ± SE, n = 4.

One-way ANOVA of initial litter chemical properties showed that tree species significantly affected the leaf litter and fine root C, N, P, C:N, N:P, and C:P (all $p < 0.05$; Table 2). Higher C, lower N and P concentrations, and higher C:N, N:P, and C:P ratios were found in the leaf litter of *C. officinarum* than that of *E. decipiens*. The fine root C, N, and P concentrations of *C. officinarum* were significantly higher, but its C:N and C:P ratios were lower than that of *E. decipiens* (all $p < 0.05$; Table 2). The fine root N:P ratio of *C. officinarum* was slightly higher than that of *E. decipiens*, although the difference was not significant ($p = 0.073$; Table 2).

Table 2. The initial chemical properties of leaf litter and fine roots (mean ± SE, n = 4).

		C. officinarum	*E. decipiens*	F-Value	*p*-Value
Leaf litter	C (%)	51.12 ± 0.49	45.23 ± 1.20	20.73	0.004
	N (mg g^{-1})	8.28 ± 0.42	10.58 ± 0.20	24.33	0.003
	P (mg g^{-1})	0.40 ± 0.03	0.67 ± 0.04	33.91	0.001
	C:N	62.20 ± 2.93	42.75 ± 0.87	40.41	0.001
	N:P	20.84 ± 0.47	16.04 ± 0.83	25.54	0.002
	C:P	1299.14 ± 84.49	687.52 ± 50.35	38.67	0.001
Fine root	C (%)	45.70 ± 1.77	38.36 ± 1.23	11.58	0.014
	N (mg g^{-1})	10.81 ± 1.86	3.27 ± 0.24	16.17	0.007
	P (mg g^{-1})	1.66 ± 0.14	0.83 ± 0.09	25.13	0.002
	C:N	46.56 ± 9.03	119.25 ± 9.77	29.85	0.002
	N:P	6.56 ± 1.18	3.97 ± 0.19	4.70	0.073
	C:P	281.3 ± 25.81	476.11 ± 52.21	11.19	0.016

Note: C, N, P, C:N, N:P, C:P refer to the litter carbon, litter nitrogen, litter phosphorus, the ratios of litter carbon to nitrogen, nitrogen to phosphorus, and carbon to phosphorus in leaf litter and fine roots, respectively.

3.2. Leaf Litter Production and Nutrient Storage

Overall, the annual leaf litter production of *E. decipiens* was significantly higher than that of *C. officinarum*. This significant difference was mainly produced by the discrepancy in the autumn. The leaf litter production of *E. decipiens* was 2.9 times as high as that of *C. officinarum* in the autumn, while there was no difference in the spring, summer, and winter (Figure 2A). In addition, there was no difference in annual leaf litter C storage between *C. officinarum* and *E. decipiens*, although it was significantly different in the autumn (Figure 2B). Nevertheless, both the annual leaf litter N and P storages of *E. decipiens* were significantly higher than that of *C. officinarum* as well as that in the spring and autumn, but no significant difference in the summer and winter (Figure 2C,D).

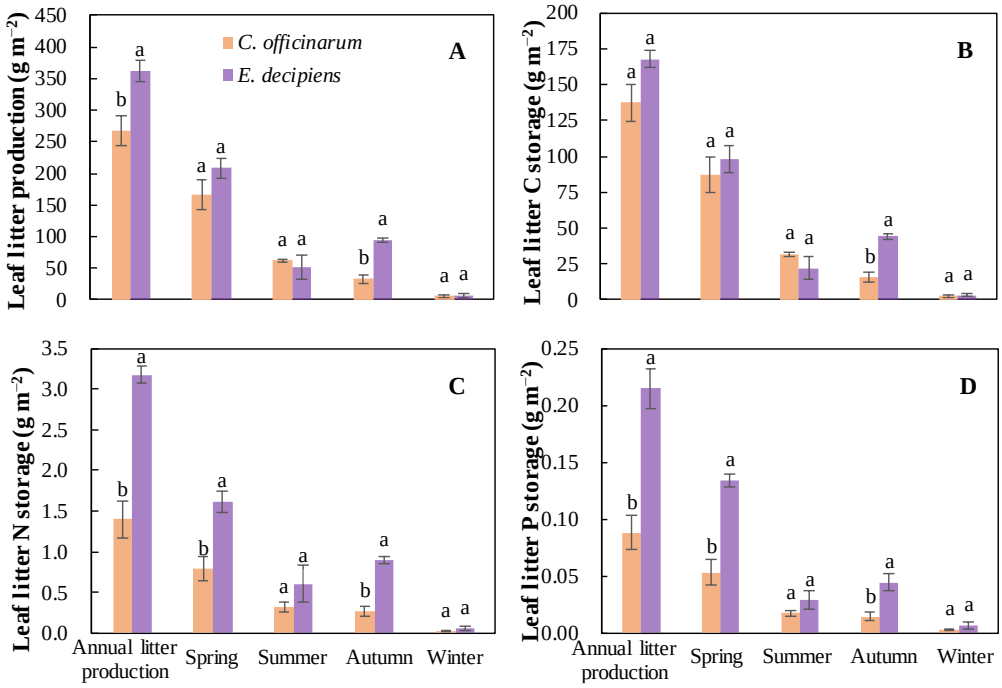

Figure 2. Leaf litter production (**A**) and their carbon (**B**), nitrogen (**C**), and phosphorus (**D**) storages in one year and different seasons. Each column is the mean ± SE, n = 4. Different lowercase letters indicate significant differences between the two tree species at the same time at $p < 0.05$ level.

3.3. Litter Decomposition

RM-ANOVAs showed that tree species significantly affected leaf litter decomposition, but not fine root decomposition ($p < 0.001$ and $p = 0.201$, respectively; Figure 3A,B). One-way ANOVA indicated that the proportion of leaf litter mass remaining of *E. decipiens* was significantly lower than that of *C. officinarum* during the first 180 days of decomposition, but the discrepancy was reduced and not significant after 270 days of decomposition (Figure 3A). The leaf litter of *E. decipiens* decomposed fast in the first 90 days; the proportions of mass remaining decreased to 72.39%, 41.21%, and 23.82% in the first 30 days, 60 days, and 90 days of decomposition, respectively. However, the leaf litter of *C. officinarum* decomposed relatively slow. Its proportions of mass remaining were 91.83%, 85.11%, and 71.71% in the first 30 days, 60 days, and 90 days of decomposition, respectively. The fast decomposition phase of *C. officinarum* was observed during the 120th to 270th day (Figure 3A). On the 450th day, the proportions of leaf litter mass remaining were 4.92% and 7.55% for *C. officinarum* and *E. decipiens*, respectively, and there was no significant difference (Figure 3A).

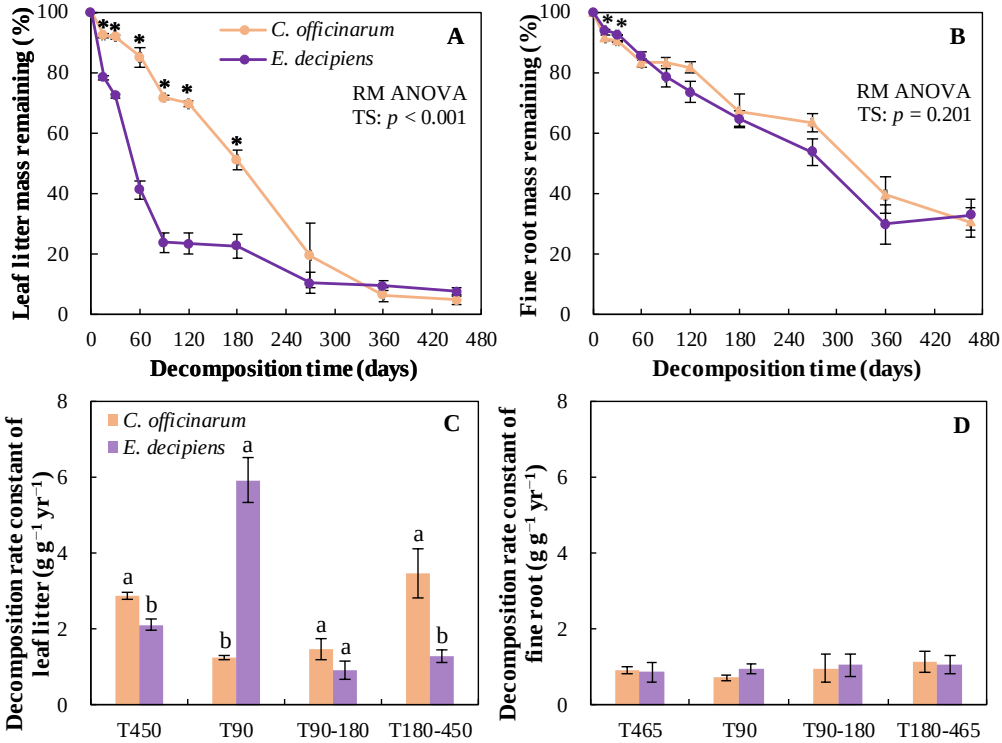

Figure 3. The proportion of initial mass remaining of leaf litter (**A**) and fine roots (**B**) during the different periods of decomposition, and the decomposition rate constant of leaf litter (**C**) and fine roots (**D**) during the 0–450/465d (T450/465), 0–90d (T90), 90–180d (T90–180), 180–450/465d (T180–450/465). Each dot and column represent the mean ± SE, n = 4. * or different lowercase letters indicate significant differences between the two tree species at the same time of decomposition at $p < 0.05$ level.

The proportion of fine root mass remaining of *C. officinarum* was lower than that of *E. decipiens* during the first 30 days (90.55% vs. 92.49%; Figure 3B). Moreover, in the first 15 days of decomposition, the proportion of fine root mass loss was high, which was 8.53% and 5.94% for *C. officinarum* and *E. decipiens*, respectively. However, there were no significant differences in the proportions of fine root mass remaining between *C. officinarum* and *E. decipiens* from the 60th to the 465th day of decomposition. The proportions of fine root mass remaining were 30.58% and 33.03% for *C. officinarum* and *E. decipiens* respectively, on the 465th day, which were 6.22 and 4.37 times the proportion of leaf litter mass remaining, respectively (Figure 3B).

The decomposition rate constants of leaf litter during the whole decomposition period and during the 180th to 450th day of decomposition were higher for *C. officinarum* than *E. decipiens*, but it was significantly lower than *E. decipiens* in the first 90 days (1.24 vs. 5.92, respectively; Figure 3C). There was no significant difference in the decomposition rate constant of fine root between the two studied tree species during the same decomposition periods (Figure 3D). Moreover, the decomposition rate constant of leaf litter was higher than that of fine root during the whole decomposition period (Figure 3C,D).

3.4. Nutrient Mineralization

Tree species significantly affected the proportions of C, N, and P remaining in leaf litter (all $p < 0.05$; Figure 4A,C,E). Specifically, a higher proportion of C remaining in the leaf litter of *C. officinarum* than that of *E. decipiens* was observed in the first 180 days. The proportions of leaf litter C remaining were 27.12% and 12.06% for *C. officinarum* and *E. decipiens* on the 180th day of decomposition, respectively. The leaf litter C loss occurred mainly in the first 270 days, only 11.56% and 7.80% of initial C storage were remained for *C. officinarum* and *E. decipiens*, respectively (Figure 4A). The proportion of N remaining was higher in the

leaf litter of *C. officinarum* than that of *E. decipiens* from the 90th day to the 180th day of decomposition. The sharp N loss occurred in the first 90 days for *E. decipiens* and during the 120th to the 360th day of decomposition for *C. officinarum* (Figure 4C). During the 60th to the 180th day of decomposition, the proportion of P remaining was higher in the leaf litter of *C. officinarum* than that of *E. decipiens*. The leaf litter P loss occurred quickly in the first 90 days for *E. decipiens*, while the P was immobilized in the first 120 days and then lost fast from the 120th to the 360th day of decomposition for the *C. officinarum* (Figure 4E).

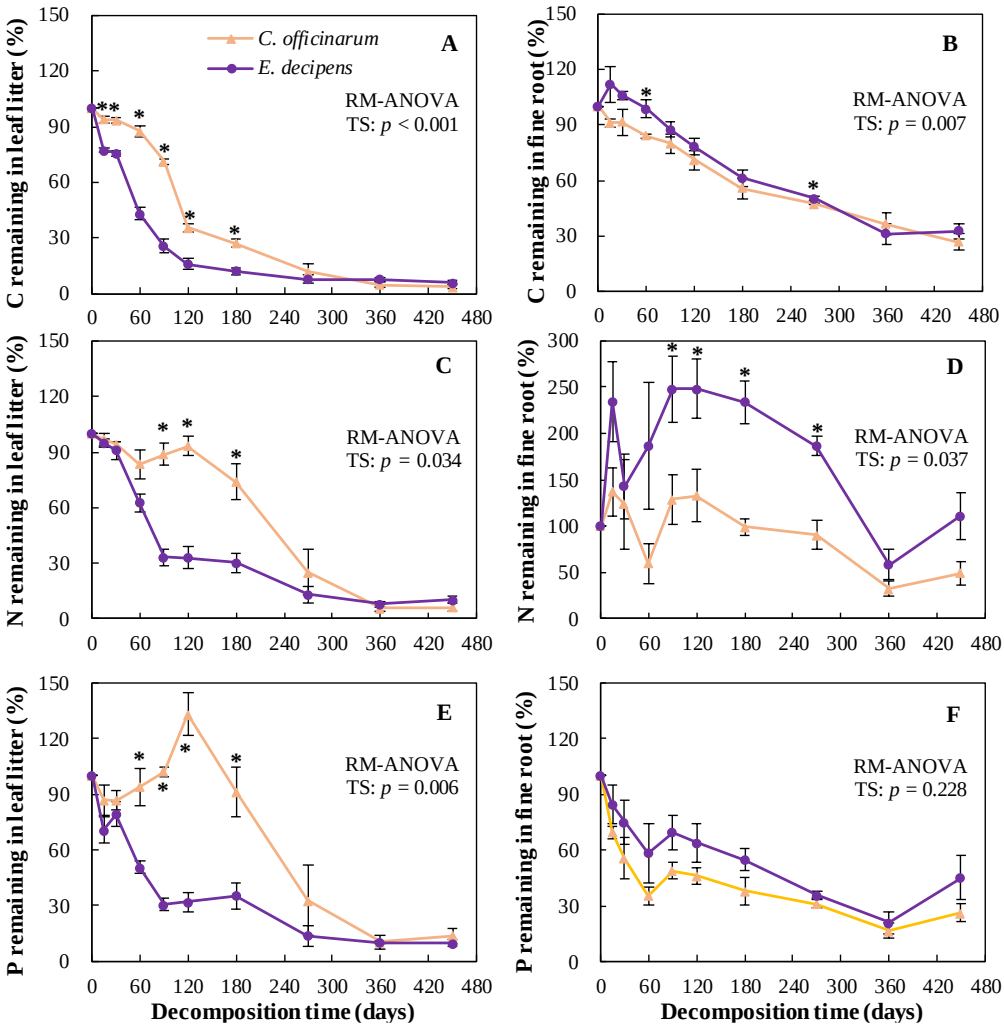

Figure 4. The proportions of initial C, N, and P remaining of leaf litter (**A**,**C**,**E**) and fine roots (**B**,**D**,**F**) during the decomposing periods. Each dot represents the mean ± SE, n = 4. * indicates significant difference between two tree species in the same time of decomposition at $p < 0.05$ level.

The proportions of fine root nutrient remaining showed contrasting patterns with those of leaf litter. RM-ANOVA showed that tree species did not significantly affect the proportions of fine root C and P remaining ($p = 0.071$ and 0.228, respectively; Figure 4B,F), but significantly affected the proportion of fine root N remaining ($p = 0.037$; Figure 4D). One-way ANOVA indicated that the proportion of fine root C remaining of *E. decipiens* was higher than that of *C. officinarum* only on the 60th and the 270th day of decomposition (Figure 4B). The higher proportion of fine root N remaining was found in the *E. decipiens* rather than *C. officinarum* during the 90th to the 270th day of decomposition, and the dynamic of fine root N showed a pattern of immobilization-mineralization-immobilization-mineralization-immobilization. On the 465th day, the proportions of fine root initial N remaining were 49.16% and 111.13% for *C. officinarum* and *E. decipiens*, respectively (Figure 4D). The dynamic of fine root P showed a pattern of mineralization-immobilization-

mineralization-immobilization, and it was not affected by tree species at any sampling time point. The proportions of fine root P remaining were 26.24% and 44.97% for *C. officinarum* and *E. decipiens*, respectively, on the 465th day (Figure 4F).

3.5. The Correlations of Initial Soil Physicochemical Properties and Litter Decomposition

The proportion of leaf litter mass remaining was positively correlated to the initial leaf litter C, C:N, N:P, SOC, soil TN, and the biomasses of bacteria, AMF and total microbes, and negatively correlated to the initial leaf litter N and P concentrations in the first 180 days of decomposition (Table S1). Additionally, the proportion of fine root mass remaining was negatively correlated to the initial fine root N and P concentrations and SOC in the first 30 days, and to the ratio of fungal to bacterial biomass on the 120th day of decomposition. Also, it was positively affected by the initial fine root C:N in the first 30 days, and the initial fine root C, N, and P concentrations on the 270th day of decomposition. However, neither soil TN nor TP significantly affected the fine root mass remaining (Table S1). In addition, the decomposition constant of leaf litter was positively correlated to initial leaf litter N and P, but negatively correlated to initial leaf litter C, C:N, N:P rations, and SOC, soil TN, and soil bacterial biomass in the first 90 days of decomposition (Table S2). However, it was negatively affected by initial leaf litter N and P, and positively by initial leaf litter C:N during the whole decomposition period (0–450 days). The decomposition constant of the fine root was only positively influenced by soil TP during the whole decomposition period (0–465 days, Table S2).

The leaf litter C remaining was positively affected by the initial leaf litter C, C:N, N:P, SOC, and soil TN concentrations but negatively affected by the initial leaf litter N and P concentrations in the first 180 days of decomposition. Soil bacterial and total microbial biomasses positively affected the leaf litter C remaining in the first 120 days, especially in the first 60 days (Table S3). In addition, the leaf litter N remaining was positively correlated to the initial leaf litter C, C:N, N:P, and SOC, but negatively correlated to the initial leaf litter N and P concentrations in the first 180 days. It was also negatively correlated to the ratio of fungal to bacterial biomass on the 270th day (Table S4). Furthermore, the leaf litter P remaining was positively correlated to initial leaf litter C, C:N, N:P, SOC, and soil TN, but negatively correlated to the initial leaf litter N and P in the first 180 days. Meanwhile, it was positively affected by soil bacterial and total microbial biomasses on the 90th day of decomposition (Table S5).

The fine root C remaining was negatively correlated to initial fine root C (in the first 120 days), SOC (on the 30th day), and soil TP (on the 450th day), respectively; and it was not significantly correlated to the initial fine root N, P, C:N, N:P, and soil microbial biomass during the studied periods (Table S3). The fine root N remaining was negatively affected by initial fine root C, N, P, and N:P in the most decomposing period, and by SOC and soil TP during the 180th to 270th day (SOC), and on the 15th and 360th day (TP), respectively. Meanwhile, it was negatively correlated to soil bacterial and actinomyces biomasses and the ratio of fungal to bacterial biomass on the 270th day (Table S4). In addition, the fine root P remaining was negatively correlated to the initial fine root P concentration in the most decomposing periods. And it was negatively affected by soil TN and TP on the 270th and 465th day, respectively, and by soil bacterial, fungal, AMF, actinomyces, and total microbial biomasses on the 270th day of decomposition (Table S5).

4. Discussion

4.1. Effect of Litter Initial Quality on Litter Decomposition

Litter quality is one of the main factors controlling litter decomposition. In this study, leaf litter mass loss was affected by initial leaf litter C, N, and P concentrations in the first 180 days of decomposition. In the early phase of decomposition, litter nutrients exert a strong influence on the mass loss of those non-lignified compounds [30]. The positive correlations between initial litter N and P concentrations and litter decomposition rate were found in other studies [14,31], which was also detected in the first 90 days of decomposition

in our study. Hence the faster decomposition rate in *E. decipiens* rather than *C. officinarum* could be partly explained by the higher initial N and P concentrations. However, in the later stage of decomposition, the initial leaf litter quality did not significantly affect litter mass loss, but the leaf litter N and P negatively affected leaf litter decomposition constant. This could be ascribed to the increase in lignin concentration with a low degradation rate [32]. The influence of lignin on litter decomposition depends on microclimate. For instance, high soil temperatures and moisture contents increased lignin and cellulose decomposition [33,34]. No difference in soil temperature between the two plots could be responsible for it in this study.

Interestingly, the effect of initial litter quality on fine root decomposition was different from leaf litter, and it only occurred in some periods. However, the initial litter quality explained why the fine root decomposition rate of *C. officinarum* with high initial N and P concentrations was faster than *E. decipiens* in the first 30 days. The initial N and P concentrations had positive effects on the fine root decomposition rate [35]. Nevertheless, the decomposition constant was not altered by fine root chemical properties even in the first 90 days of decomposition. In addition, the plant lignin content is generally higher in fine roots than that in leaf litter [36,37]. High lignin content in fine roots may lower their decomposition rate, which will make the insensitive response to the variations in initial fine root quality in most decomposition periods. It could be responsible for no difference in fine root mass loss between the two studied tree species. Moreover, the discrepancy in initial litter quality resulted in a faster decomposition rate in leaf litter relative to fine roots. The result was in accord with that reported by Guo et al. [14].

The litter decomposition is closely linked with nutrient mineralization [38,39]. The initial litter quality also affected the proportion of litter nutrient remaining in this study. The initial leaf litter C, N, P, C:N, and N:P significantly affected its C, N, and P mineralization. The differences in C, N, and P remaining between the two species thus could be partly explained. The leaf litter N was mineralized both in the *C. officinarum* and *E. decipiens*, and leaf litter P was mineralized fast in the *E. decipiens* in the early phase of decomposition. The high N and P concentration and low C:N could be responsible for them. Accordingly, the *C. officinarum* leaf litter with low P concentration first exerted a P immobilization. Spohn and Berg [39] found that P import was largely affected by the initial litter P concentration and occurred predominantly during the first months of decomposition. Moreover, the nutrient dynamics of decomposing fine roots were correlated to the initial fine root quality in this study, especially fine root N and P remaining. Pang et al. [40] concluded that litter including leaf and fine root nutrient release was mainly predicted by litter quality. That the fine root N was immobilized in the early phase of decomposition could be attributed to the high P concentration and low N:P in fine roots. It was reported that the initial P concentration and N:P affected nutrient mineralization patterns in the studies of Lin et al. and Song et al. [41,42].

4.2. Effect of Soil Chemical Properties on Litter Decomposition

Soil physical-chemical properties, such as soil organic matter, soil C:N ratio, and pH, could affect litter decomposition processes. In general, the slow decomposition rate is observed in the soil with poor nutrients, which is probably due to the low soil microbial biomass and activity. Soil N is deliberated as being the important regulating factor, while low soil N can stimulate litter decomposition and nutrient mineralization [43,44]. The SOC negatively affected leaf litter mass loss but positively affected fine root mass loss in this study. It suggested that leaf litter and fine root decomposition made diverse responses to soil nutrients, and they were regulated by different factors. The negative effects of SOC and soil TN on leaf litter decomposition rate in the first 90 days and the positive effects of SOC on fine root during the whole decomposition period supported the above conclusion. It has been reported that the drivers of decomposition differed for the leaf litter and fine roots. For example, in the initial stages of decomposition, the litter mass loss was driven primarily by precipitation for leaf litter and by temperature for fine roots [45]. Wambsganss et al. [46]

concluded that initial litter quality was the primary determinant of fine-root litter mass loss at the early stage of decomposition. Portillo-Estrada et al. [47] proposed that the leaf litter decomposition was dominated by cumulative climatic variables.

The litter nutrient mineralization could be impacted by soil nutrients. The positive effect of SOC on leaf litter C remaining was detected in this study, which could be produced by the positive correlations between SOC and leaf litter mass remaining. The litter C remaining is correlated to litter mass loss. Similarly, the fine root C remaining was negatively affected by SOC. While leaf litter P remaining was positively affected by soil N, high litter P remaining was observed in the soil with low C:N or N:P [44]. This could thus be attributable to the low soil N:P (4.6–5.9) in this study. However, the fine root C, N, and P remaining was negatively affected by soil N and P, respectively, in this study. The high nutrient remaining in the soil with low N was detected [48,49]. That is, high soil N and P could stimulate fine root nutrient mineralization and result in fast nutrient return in reverse, which could be responsible for the fine root N and P remaining in this study.

4.3. Effect of Soil Microbial Community on Litter Decomposition

The biomasses of bacterial, total microbial, and AMF negatively affected leaf litter decomposition but positively affected C and P mineralization in this study. The result was inconsistent with the positive correlations between microbial biomass and leaf litter decomposition in the study of Liu et al. [50], but non-significant correlations between them were frequently recorded in other studies [51]. The effect of soil bacterial biomass on leaf litter decomposition rate was only observed in the early phase of decomposition in this study. Microbial community composition and extracellular enzymatic activities were more important to litter decomposition and nutrient mineralization relative to microbial biomass [52,53]. The soil microbial and extracellular enzymatic activities could be higher in the *E. decipiens* soil than that in the *C. officinarum* soil in this study.

The fine root mass loss was positively affected by the F:B ratio in the early phase of decomposition. Argiroff et al. [54] found that fine root decay was positively correlated with ligninolytic saprotrophic fungi and negatively correlated with ECM fungi ligninolytic peroxidases. The ligninolytic saprotrophic fungi maybe dominate the soil fungal community. A specialized microbial network can result in faster fine root decomposition [55]. The information on soil microbial biomass and F/B ratio could partly explain the non-significant difference in fine root decomposition between *C. officinarum* and *E. decipiens* after 30 days of decomposition. The release of fine root N and P was correlated with the abundance of certain ectomycorrhizal fungi [56]. In this study, the bacterial and actinomycetes biomass and F/B ratio significantly affected fine root N and P mineralization, and the fungi and AMF affected fine root P mineralization. Therefore, the microbial biomass and community structure could be responsible for fine root nutrient mineralization in this study.

5. Conclusions

Our study demonstrated the leaf litter decomposition rate and N and P mineralization of *E. decipiens* were faster than that of *C. officinarum*, but there was no difference in fine root decomposition constant between the two studied tree species in the early phase of decomposition. However, in the whole decomposition period, the leaf litter decomposition rate of *C. officinarum* was faster than that of *E. decipiens*. In addition, both the decomposition rate and nutrient mineralization of leaf litter were faster than that of fine roots in the two tree species. The litter mass loss and nutrient mineralization were affected by soil physicochemical properties, initial litter quality, and soil microbial activity mainly in the early phase of decomposition. Moreover, the leaf litter production and N and P storages of *E. decipiens* were higher than that of *C. officinarum*, implying the nutrient return was faster for *E. decipiens* leaf litter. We therefore propose tree species with a rapid nutrient return, such as *E. decipiens*, could be more applicable to urban green space with pervious surfaces in consideration of nutrient balance. This work will improve the planning and management of urban green space.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f14091741/s1, Table S1: the Pearson correlations (r) of initial litter chemical properties, soil physicochemical properties, and soil microbial biomass with litter mass remaining (%) of leaf and fine roots; Table S2: the Pearson correlations (r) of initial litter chemical properties, soil physicochemical properties, and soil microbial biomass with decomposition constants (k) of leaf litter and fine roots; Table S3: the Pearson correlations (r) of initial litter chemical properties, soil physicochemical properties, and soil microbial biomass with litter C remaining (%) of leaf and fine roots; Table S4: the Pearson correlations (r) of initial litter chemical properties, soil physicochemical properties, and soil microbial biomass with litter N remaining (%) of leaf and fine roots; Table S5: the Pearson correlations (r) of initial litter chemical properties, soil physicochemical properties, and soil microbial biomass with litter P remaining (%) of leaf and fine roots.

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